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Discussion paper

How far do they reach? The localization of industrial and academic knowledge spillovers in the Netherlands

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Abstract

R&D is good for economic growth. There is now compelling evidence that R&D is in particular good for local economic growth, since knowledge spillovers tend to be bounded by distance. But how local is local? This paper studies the role of proximity in innovation in the Netherlands, a small country. We find that proximity does not promote industrial knowledge spillovers within the Netherlands, nor spillovers from all-discipline universities. But we do find that distance limits spillovers from universities of technology.

Keywords: Innovation, industrial spillovers, academic spillovers, geography, proximity

JEL-code: O31, R12, C24

1. Introduction

Globalization has resulted in a shift in the comparative advantage of the industrial countries towards innovative activity (OECD, 1996; Kortum and Lerner, 1997; Berman *et al*., 1997). As a result there has been an increased interest in knowledge and innovation as well in academia as in policy.[1] An important aspect of the present research and policymaking regarding knowledge development and innovation is the geographical context in which the innovation process takes place.[2] The economic-geographical or spatial-economic approach stresses the influence of networks of firms and the advantages of (spatial) clustering. Although theory and some scarce empirical studies stress the importance of proximity, 'the relevance of proximity is one of the most controversially discussed topics in the context of innovative linkages and networks' (Sternberg, 1999, 533). Theoretical concepts like the industrial district theory (Marshall, 1920; Markusen, 1996; Ottati, 1994; Rabellotti, 1998; Storper, 1992), regional innovation systems (Cooke *et al*., 1997; Malecki, 1997) and the learning region (Florida, 1995; Morgan, 1997) link geographically concentrated networks of firms to the innovativeness of these firms. The core of these economic-geographical approaches is the assumption that human interaction and physical proximity are crucial for an optimal transfer of knowledge. Case studies of Silicon Valley (Saxenian, 1994), Third Italy (e.g. Storper, 1993) and Baden-Württemberg (e.g. Sternberg, 1999) are often used to underpin the importance of proximity. Empirical studies for the United States also stress the importance of proximity (Audretsch and Feldman, 1996; Jaffe *et al*., 1993; Feldman, 1994). The question arises whether the same holds true for a small country like the Netherlands, which measures 41,160 squared kilometres, 1/227 of the size of the US . This question is important because current industrial policy in the Netherlands is partly based on the assumption that proximity is important for the promotion of

[1] The creation and dispersion of knowledge is a central theme of the theory of endogenous economic growth (Romer, 1990, 1994) and has resulted in an impressive amount of empirical studies that build upon this modern growth theory.

[2] This interest has resulted in a number of special issues on subjects like learning, innovation and proximity in journals. E.g. see Regional Studies (vol 33.4, 1999) and the Cambridge Journal of Economics (vol. 23, march 1999).

innovation.

This study contributes in several ways to the empirical literature on proximity and innovation. First, it offers an empirical approach towards the relationship between innovativeness, spillovers and geography for a small European country, whereas most other empirical studies focus on the United States (Audretsch and Feldman, 1996; Jaffe *et al*., 1993; Feldman, 1994). As far as we know, no empirical study on proximity and innovativeness for the Netherlands on a whole has been performed. Second, the study goes beyond case studies. Previous studies in this tradition have mostly examined the relationships referred to above in a descriptive way by doing case studies and/or using descriptive statistics (Gray *et al.*, 1996; Kaufmann and Tödtling, 2000; Longhi, 1999). Third, the focus of the paper is not to describe the advantages of clustering, but instead tries to measure the relationship between geographical proximity and innovativeness. We use a new data set on innovation and apply a fresh postal code based approach to measure distance.

Furthermore, the paper contributes to the literature on university-firm relations. The role of higher education is changing. The growing importance of knowledge and information enhances the role of universities. They are not only seen as producers of knowledge, but also as a tool for regional development (Thanki, 1999). We test whether the presence of a university in a region creates spillovers and positively affects the innovativeness of neighbouring firms.

The empirical findings can be summarized as follows; (1) We do not find evidence that proximity matters for spillovers in the Netherlands; (2) We do find evidence that the presence of a university of technology is positively related to the innovativeness of neighbouring firms.

The paper is structured as follows. In Section 2 we discuss the literature on innovation, knowledge spillovers and geography and we summarize this literature into two hypotheses. In Section 3 we develop the ring-model of proximity that pins down the relationship between spillovers, distance and innovativeness. Section 4 presents the data set and Section 5 the model specifications. In Section 6 we present the estimation results and in Section 7 we look for evidence that proximity matters for knowledge spillovers. Section 8 concludes with a discussion of our results.

2. Knowledge spillovers and geography

A central element of theories of innovation is the concept of knowledge spillovers. Griliches (1979, 1992) distinguishes two kinds of spillovers: rent spillovers and (pure) knowledge spillovers. Rent spillovers arise when quality improvements by a supplier are not fully translated into higher prices for the buyer(s). Productivity gains are then recorded in a different firm or industry than the one that generated the productivity gains in the first place. Rent spillovers occur in input-output relations. Pure knowledge spillovers refer to the impact of the discovered ideas or compounds on the productivity of the research endeavours of others. Pure knowledge spillovers are benefits of innovative activities of one firm that accrue to another without following market transactions.

In order to understand the relationship between knowledge spillovers and the geographic clustering of innovative activities it is useful to make a distinction between different kinds of knowledge. The OECD (1996) distinguishes knowledge as a set of skills and competences and knowledge as more or less complex information. Know-what and know-why refers to knowledge about facts and scientific knowledge - codified knowledge, while know-how and know-who - tacit knowledge refer to (social) skills. While know-what and know-why can be obtained through reading books and blue-prints, know-who and know-how is learnt in social relationships. Therefore, know-what and know-why can easily be transferred through technological information infrastructures, while transmission of know-who and know-how require close human interaction.

Marshall (1920) and Krugman (1991, 1998) both argue that geography may matter because of tacit knowledge. Tacit knowledge is vague and difficult to codify and while the marginal cost of transmitting information or codified knowledge across geographic space fall under the influence of new developments in information and communication technology, the marginal cost of transmitting tacit knowledge rises with distance (Audretsch 1998). As tacit knowledge and human interaction become more valuable in the innovation process geographical proximity becomes crucial to the innovation process.

Maskell *et al*. (1998) offer a second reason for the link between proximity and the transfer of tacit knowledge. This is related to proximity in a social and cultural sense. The exchange of tacit knowledge may require a high degree of mutual trust and understanding and a common language and shared norms and values may play a important role in this context. Similar arguments can be found with Nooteboom (1999). Following this line of reasoning, Lawson and Lorenz (1999) explicitly link tacit knowledge to regional competitive advantage.

Up till the 1990's, the empirical evidence on the importance of proximity is scarce. As Jaffe *et al*. (1993, 578) remark 'the existing spillover literature is virtually silent on this point'. Since then a number of empirical studies appeared. Jaffe *et al*. (1993) compare the geographic localization of patent citations with that of the cited patents, as evidence of the extent to which knowledge spillovers are geographically localized. They find that, although localization slowly fades over time, a US patent tends to be cited more frequently within the state in which it was filed than outside the state. Feldman (1994) finds that product innovations exhibit a pronounced tendency to cluster geographically. She also concludes that the geographic clustering of product innovations at the state level is related to the level of industry R&D and university R&D expenditures in the state, which is consistent with earlier findings of Jaffe (1989). In an empirical study on the spatial distribution of innovative activity in the United States Audretsch and Feldman (1996, 639) find that 'even after controlling for the concentration of production we find evidence that industries in which knowledge spillovers are more prevalent - that is where industry R&D, university research and skilled labour are the most important - have greater propensity to cluster than industries where knowledge externalities are less important'. They conclude that while the cost of transmitting information may be increasingly invariant to distance, presumably the cost of transmitting tacit knowledge rises with distance. Kelly and Hageman (1999) find that the location of sector's R&D activity is determined more by the location of other sectors' innovation than by the location of its own production; Carrincazeaux et al (2001) however find evidence for the opposite thesis. Adams and Jaffe (1996) find that R&D in the same state or within a radius of 100 mile is more potent than distant R&D of the same firm. Though most of the empirical papers mentioned above focus on American states, Anselin et al. (1997) use a lower level of analysis (metropolitan statistical areas) by means they claim to avoid some problems associated with the spatial scale of a state as a unit of analysis. When studying the spatial extent of the local geographic effects that university research may have on the innovativeness of a region, they find that local spatial externalities are present and important.

Besides knowledge-intensive firms, universities play a central role in the process of knowledge creation and dispersion. Both the knowledge spillovers stemming from the production of knowledge, but also the development of human capital are assumed to be important attractors for private sector R&D and high-technology production (Malecki, 1997). Or as Florax puts it, universities may serve as 'regional boosters'. Moreover, Adams (2001) finds that academic spillovers are more localized than industrial spillovers. Using data on US research and development laboratories, Adams argues that localized academic spillovers encourage firms to work with local universities, which contrasts with relations between firms, where contractual arrangements are needed to access proprietary information, often at a considerable distance.

Hence, a tentative conclusion of the theory and the empirical studies is that knowledge spillovers become less important with increasing distance. Proximity and location matter in the transmission of knowledge. There is a positive relationship between proximity of R&D and a firms' innovation performance (cf. Echeverri-Carroll and Brennan, 1999). Or as Feldman and Audretsch (1999, 410) put it, 'new economic knowledge may spill over, but the geographical extent of such knowledge spillovers is bounded'.

However, the question arises whether the same holds true for the Netherlands. As earlier noted , this question is important because Dutch industrial policy is partly based on the assumption of the importance of proximity in order to stimulate innovativeness. And as Florax and Folmer argue after finding no clear proximity effect in academic knowledge production, 'for countries of the scale of the Netherlands, further empirical research is required before implementing far-reaching changes in the spatial knowledge infrastructure so as to stimulate regional development' (Florax and Folmer, 1992, 457). Therefore, we formulate the following hypotheses and test them with Dutch data:

Hypothesis 1: Physical proximity facilitates knowledge spillovers between firms.

Hypothesis 2: The presence of a university positively affects the innovativeness of neighbouring firms.

3. Modelling proximity

To test the above mentioned hypotheses we develop a so-called 'ring-model' of proximity, that resembles the traditional Von Thunen (1826) rings. In this way we are able to test the idea that distance reduces the ability to receive knowledge.

< Insert Figure 1 about here >

We define a number of geographical rings around each firm *j*. In the ideal case we define the rings around firm *j* on the base of equal costs of distance. The time to travel from *j* to any other firm on the edge of the first, resp. second and third ring is the same. The resulting rings around *j* are not symmetrical but by doing so we specify the concept of proximity for every firm *j* in a consistent way.

An alternative approach is to define the rings on the base of a consistent measure of distance in kilometres. Around *j* rings arise with a radius of equal kilometres. The first ring covers the firms within a distance of eg. 0-10 kilometres around *j*, the second ring covers the firms within a distance of 10-20 kilometres around *j*, etc. Unfortunately, we do not have the right information to compute neither the physical distance nor the time-related equivalent. We have no data about the time dimension of distance and the problem that arises by applying the kilometre-method is that rings cross zipcode areas and that innovation data (that are linked to these zipcode areas) cannot be fitted in the rings in a proper way. But we do know the firms' zipcode, which reveals information about a firm's location.

Therefore we choose to take the Dutch zipcode structure as our basis of analysis. Dutch postal codes are hierarchic and range from 1000 to 9999. The first ring is the geographical area with the same three-digit postal code as firm *j*, the second ring consists of the area with the same two-digit postal code, and the third ring the one-digit postal code area, see figure 1 [3]. For example, firm *j* has the postal code 3425. This implies that the first ring, which includes the closest neighbouring firms, is defined as the postal code area numbered 342. Hence, the first ring includes all firms with postal codes between 3420 and 3429. The second ring is the postal code area 34 and includes al firms with codes between 3400 and 3499. The third ring, the firms that are most far off, consists of all the firms that are in area 3. Statistics Netherlands has restricted the level of analysis to the three digit level for reasons of confidentiality. This implies that the finest level of analysis is the three digit level.

Several problems arise when using the above definition of rings. First, As a result of historical and pragmatical reasons Dutch zipcode areas on the same digit level are not of equal size. This implies that if we take the absolute level of R&D of a firm and add these levels of R&D in the different rings, large zipcode areas have a larger impact than zipcode areas that are relatively small. This size-effect is reduced because of the fact that there is a size difference between postal code areas in rural and urban areas. Urban areas with more firms are in general smaller than rural areas with less firms.

Moreover, if we would control for this size effect by measuring *relative* R&D expenditures of firms, the problem arises that the impact of large R&D intensive companies like Philips, Shell, Unilever, Akzo and DSM is levelled out. And we expect the impact of the innovation expenditures of a great firm like Philips on the surrounding firms to be much greater than the impact of a relatively small firm.

A second problem concerning the use of the zipcode areas as the base for our rings, is the fact that some firms

[3] Note that the ring model is an approximation of geographical distance. Postal code areas differ in geographical size. In reality, the system of rings is not as symmetric as figure 1 suggests.

have one or more subsidiaries. If this is the case, it is not known where the firm undertakes its R&D. We assume that the R&D is concentrated in the main location, from which we know the postal code.[4]

4. Data

We use a unique database from Statistics Netherlands (CBS). The data set includes firm-level information about innovation from the 1996 CIS2 (Community Innovation Survey) survey and information about location (postal codes) from the Firm Administration Register. The set consists of non-service firms. Making use of the above described ring-model, we relate the innovative output of firm *j* to its own innovation expenditures, the innovation expenditures of the firms in the first ring *k* (excluding the expenditures of firm *j*), the expenditures of the firms in the second ring *l* (this excludes the expenditures of the firms in the first ring and of firm *j*), and the expenditures in the third ring *m* (this excludes the expenditures in the first and the second ring and the expenditures of firm *j*).

The data set we use consists of 1510 firms. The average amount of innovation expenditures per firm equals 4 million guilders, but declines because a large part of the Dutch innovation takes place in a relative small amount of firms. The distribution of innovation expenditures and innovative output over three categories of size of the firms in the sample is given in table 1. The total amount of innovation expenditures of these 1510 firms equals 6.7 billion guilders. The share of new products in total sales equals approximately 8 %; the share of new and improved products in total sales is about 27 %.[5]

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[4] An additional problem concerns the transformation of a four-digit zipcode to the three digit level. The lowest level of zipcode areas in the Netherlands is the four digit level. A simple transformation to three digit level is not possible in some cases, because several three digit level zipcode areas exist with the same code . If there are two three digit areas it is impossible to connect the innovation data of a firm to a unique location in the Netherlands. Therefore we have re-coded the ‘double’ three digit areas, based on the four digit code. In this way we are able to give every firm a unique (three digit) location in the Netherlands.

[5] ‘New’ and ‘improved’ refers to the technology embodied in the product.

< Insert Table 1 about here >

The presence of a university

The second hypothesis referred to the presence of a university. We pose that firm *j* is in the neighbourhood of a university if the firm and the university have the same postal code at the two-digit level. The Dutch educational system is geographically dispersed (cf. Wever and Stam, 1999). Universities are evenly spread over the country. That is the main reason to measure presence of a university at the two digit postal code level. If we would take the one-digit level, variance is too small, and by taking the three digit level, the geographical areas on which we expect a university to have impact is very small.

We distinguish between general and technical universities. There are 14 universities in the Netherlands including the ‘private’ university of Nijenrode. Three of them provide technical studies: Delft University of Technology, Eindhoven University of Technology and Twente University of Technology. The frequency of firms being in the same two digit postal code area of a university of technology is lower than the frequency of firms in the neighbourhood in the presence of a general university. To summarize, out of 1510 firms in total, 110 are located close to a university of technology (7.3 %) and 177 firms are located close to a general university (11.7 %).

University a source of information

The second way we test for the possible influence of a university on the innovative output of a firm is by taking up a dummy that measures contact with a university. The data do not allow us to specify between technical and general universities. Therefore we include a dummy measuring whether or not firm *j* has contacted a university during the innovation process. Of the 1510 firms, 464 (30.7 %) have contacted a university during the innovation process. If we compare the different classes of firms in terms of size (see table 1), we observe that the propensity of firms contacting the university increases when firms are larger.

Control variables

We also include a number of other variables. Some of them are routinely found in the empirical literature on innovation [6]. The first one is a dummy indicating whether the firm received a subsidy to finance the innovation process. As is illustrated in table 1, more than half of the firms in the sample makes use of financial support of the government. The group of large firms reaches a level of 70%, whereas the amount of relatively small firms that asked for subsidy is just somewhat more than 40%. Apparently, larger firms make more use of the subsidy instrument of the government in the Netherlands.

Second, we add a variable measuring the export orientation of the firm. The theoretical argument refers to the level of competition. The idea is that exporting firms face stronger competition and thus more incentives to innovate to continue their activities in the international markets. Hence, exporting activities will have a positive effect on innovative output. Table 1 clearly shows that larger firms tend to export more in relative terms. Small firms (10-49 employees) export on average 25 % of their sales, and the group of large firms exports half of its sales.

Third, we control for firm size. The firm-size variable captures the idea that large firms are able to benefit from economies of scale and scope in the innovation process. Firm-size is measured as the number of employees of the firm.

Fourth, we control for region-specific effects. Characteristics of a region may influence the innovative capabilities of a firm. Thick labour markets, well-developed physical infrastructures (e.g., roads and airports), tailored social capital (e.g., entrepreneurial spirits), and well-functioning capital markets are examples of regional characteristics that could benefit the innovation process. We define the one-digit postal code area in which firm j is located as the region of firm j.

[6] See e.g. the papers presented at the TSER workshop on "Innovation and Economic Change", Delft University of Technology, February 12-13, 1999.

Finally, we include sector dummies to control for sector-specific effects, since for some industries the natural propensity to innovate might be larger than in other industries. Sector dummies are constructed using two-digit SBI-code level (SBI is the Dutch equivalent of SIC).

5. The model

Our model explains a firm's innovative performance from its expenditures on innovation, the expenditures on innovation of other firms that are located very closely, closely, and not-so-closely to the firm, and the presence of a university (of technology) nearby. The model controls for firm characteristics such as firm size, export focus, links with universities, region, sector, and subsidy status.

The two variables that are available in our database to measure innovative performance - share of new products in turnover respectively share of new and improved products in turnover - take continuous values between zero and one. We observe a substantial number of firms that have an innovative performance equal to zero, and a few that perform at the upper bound of the interval. The functional form that suggests itself is therefore the two-sided censored Tobit model (e.g. Maddala, 1983, and Greene, 2000, 908). Let y^* denote the latent variable, indicating non-observed innovative performance, let y denote observed innovative performance, let x denote the vector of explanatory and control variables, and let u denote an i.i.d. normally distributed error term with mean zero and variance σ^2. Then the model reads as follows:

$$y^*_i = \beta' x_i + u_i, y_i = 0 \; if \; y^*_i \leq 0, y_i = y^*_i \; if \; 0 < y^*_i < 1, y_i = 1 \; if \; y^*_i \geq 1$$

where y denotes the share of new product in turnover respectively share of new or improved product in turnover, and x denotes a vector of explanatory and control variables consisting of the following variables:

Constant	constant
INNOVEXP	the log of the expenditures on innovation of firm *i*
INNOVEXP3	the log of the expenditures on innovation of firms located in the 3-digit postal code area of firm *i*, excluding firm *i*'s expenditure
INNOVEXP2	the log of the expenditures on innovation of firms located in the 2-digit postal code area of firm *i*, excluding the expenditures of firms located in the 3-digit postal code area of firm *i*
INNOVEXP1	the log of the expenditures on innovation of firms located in the 1-digit postal code area of firm *i*, excluding the expenditures of firms located in the 2-digit postal code area of firm *i*
TECHUNIV	university of technology is located in the 2-digit postal code area of firm *i* (dummy)
	a non-technical university is located in the 2-digit postal code area of firm *i*
NONTECHUNIV	(dummy)
	firm *i* has contacted a university during the innovation process (dummy)
LINKUNIV	firm *i* has received a subsidy to perform activities aimed at innovation (dummy)
SUBSIDY	the log of the workforce of firm *i*
SIZE	the log of the export share in the turnover of firm *i*
EXPORT	a set of 9 dummies measuring region-specific factors; a region is a 1-digit postal
REGION	code area
	a set of 28 dummies measuring sector-specific factors using the SBI industry
SECTOR	classification

The likelihood function of this model reads

$$L(\beta,\sigma|y_i...y_n,X_i...X_n) = \prod_{i:y_i=0}[\Phi(\frac{0 - X_i\beta}{\sigma})]\prod_{i:0<y_i<1}[\frac{1}{\sigma}\phi(\frac{y_i - X_i\beta}{\sigma})]\prod_{i:y_i=1}[1 - \Phi(\frac{1 - X_i\beta}{\sigma})] \tag{1}$$

where ϕ and Φ denote the density respectively distribution function of the standard normal distribution. Maximizing $L(\beta,\sigma|y_i...y_n,X_i...X_n)$ with respect to β and σ yields maximum likelihood (ML) estimates of the impact of the explanatory and control variables on the (latent) dependent variable, and an estimate of the variance of the error term. Hence, given the characteristics X of firm *i* and given (the ML-estimates of) the parameters β and σ, the model gives us a probability distribution of the innovative performance y of firm *i*. For values between zero and one, this distribution mimics the normal distribution. For zero-performance or 100%-performance, we have an atom in the distribution that is equal to the mass in the left respectively right tail of the normal distribution, censored at zero respectively one. The parameters β should be interpreted as the contribution of the explanatory variables in the explanation of the variance in the endogenous variable. These parameters report the change in the share of innovative products in turnover that is to be associated with a percentage change in the expenditures on innovation.

Even though the two-sided censored Tobit model seems to be a good functional form on a priori grounds, we also estimate two simple alternative specifications. The linear regression model reads

$$y_i = \beta' x_i + u_i \qquad (2)$$

The logit model reads

$$\log \frac{y_i}{1 - y_i} = \beta' x_i + u_i \qquad (3)$$

In both models, *y* denotes innovative performance, *x* the vector of explanatory and control variables, and *u* the i.i.d. normally distributed error term with zero mean and variance σ^2. Ordinary least squares estimation produces estimates of β and σ.[7]

[7] Moreover, we relaxed the assumption that the standard deviation of the error term is constant for all firms in order to investigate whether heteroskedasticity introduces important biases in the estimation results. We did not find evidence for such biases.

6. Estimation results

This section reports on the estimation result. Columns (1) and (4) of Table 2 display the maximum likelihood estimations of the Tobit model explaining the share of new products in turnover respectively the share of new or improved products in turnover. The other columns show OLS estimation results for the linear regression model and the logit model.

< insert table 2 about here>

We find a consistently positive impact of own innovative expenditures on innovative output. Innovative expenditures by firms located nearby, however, do not have a consistently significant impact on innovative performance. At best, we find weak evidence for a positive impact of innovative expenditures of firms that are located a relatively long way off, on the share of new products in turnover.

It should be noted that the insignificant impact of innovative expenditures by nearby firms on a firm's innovative output does not imply that knowledge spillovers are absent. The point is that we simply cannot measure the impact of innovative expenditures of firms located outside a firm's one-digit postal code area (and of expenditure in foreign countries), because variability in those expenditures is lacking. To put it differently, the impact of those expenditures is captured by the constant term.[8]

We do find some evidence for a positive impact of locating close to technical universities. Since we control for an established link between firm and university, the impact of the TECHUNIV explanatory variable hints at benefits attributable to knowledge spillovers or other types of agglomeration economies that can be associated with technical universities. Interestingly, the positive impact of location of universities is restricted to technical universities and to new product, rather than to general universities and to improved products.

[8] Indeed, Jacob, Nahuis and Tang (1999) find significant intra national intersectoral R&D-spillovers for the Netherlands.

Subsidies are significantly and positively correlated with innovative output; note that causality might run from innovation to subsidy. Firm size has a negative impact on innovation. This is consistent with earlier findings that small innovative firms have a higher degree of innovation than large innovative firms, although large firms are more likely to be innovative than small firms (Hansen, 1992).

7. Does proximity matter?

Does proximity matter for industrial knowledge spillovers? We draw inference from the differences in the coefficients measuring the impact of innovative expenditures on the firm's innovative performance. Indeed, the larger the estimated impact of innovative expenditures nearby compared to the impact of expenditures located far away, the more support for the thesis that proximity facilitates knowledge spillovers.

Straightforward calculation of the difference between coefficients reveals whether a 10%-increase in expenditures of distant firms has a smaller impact on firm *i*'s innovative performance than a 10%-increase in expenditures of the firms located nearby. (A confidence interval can be constructed using the estimated variance-covariance matrix of the two coefficients.) Such calculations do not suggest that proximity matters for knowledge spillovers, but we do find that the impact of own expenditures on innovation is significantly larger than the impact of expenditures by others firms (see appendix A for details).

However, we are not interested in the difference in impact of a 10%-increase in innovative expenditure, but in the difference in impact of a guilder spent on innovation. Direct estimation (e.g. OLS with levels of expenditure as explanatory variables) does not produce sound estimates. Still, indirectly, we can compute an estimate of the difference in impact of a guilder from the estimated elasticities reported in table 2.

The impact of a marginal expenditure of surrounding firms on the innovative output of firm i is equal to the derivative of firm i's innovative output with respect to the expenditures on innovation by those surrounding firms. We algebraically computed these derivatives for the three specifications. Then, for each firm i in our data set, we computed the impact of an additional guilder on innovation by firms located very closely, closely, and not-so-closely to firm i with help of the estimated elasticities. Next, we averaged the impact of a guilder expenditure of, say, firms nearby over all firms and computed the sample variance.[9] Table 3 reports the results of these calculations.

< insert table 3 about here>

We conclude from table 3 that our analysis does not show evidence that proximity matters for knowledge spillovers. The importance of proximity varies so widely over firms that we can not tell the estimate of the difference in impact of an additional guilder different from zero. Point estimates of the average difference in impact are often even negative.

8. Conclusions and discussion

We have searched for empirical evidence of the importance of proximity for knowledge spillovers in the Netherlands. We were unable to find support for the hypothesis that innovative expenditures by nearby firms have a larger impact on a firm's innovative performance than those by firms that are located further away. This evidence therefore does not provide support for generic policies that aim to concentrate innovative activities in a small country at specific geographical zones. We do find evidence of a positive correlation between a firm's innovative performance and the near presence of a university of technology. These conclusions match those of several other contributions to the literature (Adams, 2001, Anselin et al, 1997, Mansfeld and Lee, 1996). But also studies in the Netherlands find similar results as we do with respect to the importance of proximity. Oerlemans *et al*. (1998, 2001) study manufacturing firms in the South-east - Brabant region and

[9] One may want to weight the marginal impact with the innovative expenditure of the firm itself. The idea is that the case of a large R&D spender (e.g. Philips) may need to weight more than the case of a firm spending small sums on innovation (e.g. a small engineering firm). In the case of the Netherlands such a procedure is not very helpful, since the five or six firms that dominate the Dutch R&D landscape would completely determine the outcomes.

conclude that innovative relations with buyers and suppliers located in the southern part of the Netherlands are just as knowledge intensive as relations with buyers and suppliers located in other areas. Wever and Stam's (1999) study on Dutch SMEs suggest that the majority of the firms have nationwide linkages. The Netherlands Economic Institute compared localisation preferences of knowledge intensive firms with non-knowledge intensive firms (NEI, 1999). They found that differences are very small. For both types of companies proximity to knowledge centres is not considered very important, whereas a 'traditional' factor like accessibility is regarded as most important. Hence, these studies agree with ours that there is no empirical support for a broad statement that proximity matters for knowledge spillovers.

In specific spatial contexts, however, the proposition that proximity matters for knowledge spillovers might hold true. For example, there is evidence that if regions are defined as areas of the size of a two-hour train trip, proximity does matter (Audretsch and Feldman, 1996; Jaffe *et al*., 1993; Feldman, 1994). For a small country such as the Netherlands, a two hour trip by train would imply a journey into its neighbouring countries Germany or Belgium. This study thus suggests that the Netherlands is too small a country to have proximity play the leading role in facilitating knowledge spillovers. This conclusion might a fortiori hold for other regions of similar size.

Moreover, it should be noted that this study focusses on the impact of proximity on knowledge spillovers in general. A similar analysis with innovative expenditures disaggregated into specific types and sorts could reveal an impact of proximity for a selected set of expenditures. For example, proximity might be important for spillover of technologies in field A while being unimportant for technologies in field B. Key externalities might occur between firms that engage in a narrow field of R&D (Henderson *et al*., 2001).

Also, a focus on highly tacit types of knowledge might disclose a substantial role for proximity. Furthermore, several scholars have argued that organizational proximity may be more relevant than geographical proximity (see, e.g. Torre and Gilly, 2000). Knowledge spillovers need the support of transmission channels such as buyer-supplier relations, firm-university relations, sectoral business organizations, and labour market turnover, and geographical proximity may not be the major explanation for who a firm connects to. Disaggregation could be implemented in the empirical framework presented in this paper through the construction of a (weighted) measure of *relevant* innovative expenditures. Innovative expenditures by firm *j* in ring *k* might be considered relevant for the innovative activities of firm *i* if firm *i* and *j* are active in the same industry or if (regional) input-output tables reveal a relation between firm *j*'s and firm *i*'s industry.

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Appendix A: Estimates of differences in impact

Tables A.1-A.3 report estimates of the differences in impact of percentage changes (i.e., elasticities) in innovative expenditures at different distance on a firm's innovative performance.

< insert table A.1-A.3 about here>

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Figures:

figure (1)

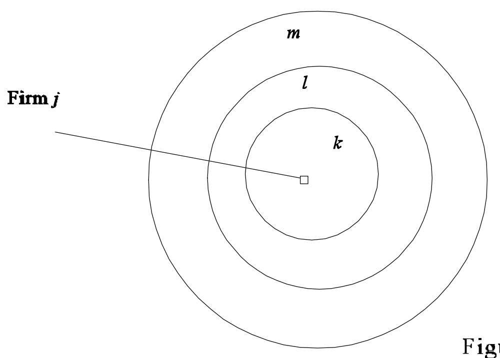

Figure 1

Table 1. Descriptive statistics

Number of employees	Average innovation expenditures (in thousands guilders)	Average share of new products in total sales	Average share of new and improved products in total sales	Mean of firms contacting a university	Mean value of firms that make use of subsidy	Mean value of share of exports in total sales	Number of firms
0-49	423.68	0.092	0.27	0.17	0.42	0.26	458
50-199	1123.59	0.077	0.26	0.32	0.57	0.41	777
> 200	20547.87	0.085	0.28	0.48	0.72	0.51	275
Total	4448.83	0.0832	0.27	0.3	0.55	0.38	1510

Table 2. Firm-level innovative performance explained by innovative environment

dependent variable:	Share of new products in turnover			Share of new or improved products in turnover		
Variables	Tobit (1)	OLS (2)	Logit (3)	Tobit (4)	OLS (5)	Logit (6)
Constant	-0.802 (-1.39)	-0.175 (-0.44)	-18.20 (-2.33)	-0.179 (-0.20)	0.203 (0.25)	-9.78 (-0.91)
INNOVEXP	0.0242 (7.00)	0.0183 (7.85)	0.284 (6.11)	0.0550 (10.11)	0.0494 (10.35)	0.504 (7.83)
INNOVEXP3	0.00098 (0.36)	0.00085 (0.45)	-0.0113 (-0.30)	-0.00292 (-0.68)	-0.00188 (-0.49)	-0.0833 (-1.61)
INNOVEXP2	0.00066 (-0.13)	-0.00324 (-0.90)	0.0184 (0.26)	-0.00133 (-0.16)	-0.00494 (-0.67)	0.0529 (0.53)
INNOVEXP1	0.0506 (1.46)	0.0180 (0.76)	0.828 (1.76)	0.0202 (0.37)	0.00229 (0.048)	0.394 (0.61)
TECHUNIV	0.0419 (1.81)	0.0153 (0.95)	0.819 (2.55)	0.00715 (0.19)	0.00081 (0.025)	0.162 (0.36)
NONTECHUNIV	0.00703 (0.47)	0.00213 (0.21)	0.0665 (0.33)	-0.0114 (-0.48)	-0.00825 (-0.40)	-0.246 (-0.88)
LINKUNIV	0.0217 (2.16)	0.0146 (2.07)	0.297 (2.12)	0.0348 (2.15)	0.0341 (2.38)	0.266 (1.37)
SUBSIDY	0.0428 (4.39)	0.0202 (3.02)	0.668 (5.01)	0.0746 (4.82)	0.0551 (4.03)	0.953 (5.17)
SIZE	-0.0239 (-4.56)	-0.0194 (-5.45)	-0.197 (-2.77)	-0.0517 (-6.25)	-0.0470 (-6.45)	-0.464 (-4.73)
EXPORT	-0.00213 (-0.69)	-0.00122 (-0.58)	-0.0224 (-0.53)	-0.00298 (-0.61)	0.00023 (0.053)	-0.0973 (-1.67)
R-squared		0.13	0.14		0.17	0.14
adjusted R-squared		0.11	0.12		0.15	0.12
F-statistic		4.94	5.5		6.79	5.52
Number of obs.	1510	1510	1510	1510	1510	1510

Notes: See text for explanation of the abbreviations of variable names.

Asterisks mark coefficients whose t-statistics indicate statistical significance from zero in a two-tailed test at the 5% level (one asterisks) respectively 10% level (two asterisks).

We do not report the estimation results for the region and sector dummies.

Table 3. Does proximity matter for knowledge spillovers? Estimates of differences in impact

dependent variable:	Share of new products in turnover			Share of new or improved products in turnover		
average difference in impact of an additional guilder spent by firms located	Tobit (1)	OLS (2)	Logit (3)	Tobit (4)	OLS (5)	Logit (6)
very closely vs. closely	7.7 (41.3)	10.5 (65.2)	-6.7 (52.0)	-20.0 (140.3)	-7.9 (124.8)	-91.4 (606.0)
closely vs. not-so-closely	-1.5 (10.9)	-4.3 (46.4)	1.6 (33.3)	-1.8 (18.8)	-6.3 (70.8)	7.7 (110.6)

Notes: Estimates have been multiplied by 1.0E+07, hence numbers report differences in impact of an additional 10 million guilders spent on innovation. Sample standard deviations in between brackets.

Table A.1. Does proximity matter for knowledge spillovers? Estimates of differences in impact (of percentage changes), two-sided censored Tobit model

Upper triangle: share of new products in turnover
Lower triangle: share of new and improved products in turnover

	INNOVEXP	INNOVEXP3	INNOVEXP2	INNOVEXP1
INNOVEXP		0.0232 (5.19)	0.0235 (3.81)	-0.0264 (-0.76)
INNOVEXP3	0.0521 (7.38)		0.000318 (0.06)	-0.0497 (-1.44)
INNOVEXP2	0.0537 (5.47)	0.00159 (0.18)		-0.0500 (-1.59)
INNOVEXP1	0.0348 (0.63)	-0.0173 (-0.32)	-0.0189 (-0.38)	

Notes: Upper triangle: entries denote estimates of the impact of the row-variable minus the impact of the column-variable on the share of new products in turnover. Lower triangle: entries denote estimates of the impact of the column-variable minus the impact of the row-variable on the share of new and improved products in turnover.

See text for explanation of the abbreviations of variable names.

t-statistics of differences in brackets. Asterisks mark differences whose t-statistics indicate statistical significance in a two-tailed test at the 5% level (one asterisks) respectively 10% level (two asterisks).

Table A.2. Does proximity matter for knowledge spillovers? Estimates of differences in impact (of percentage changes), linear regression model

Upper triangle: share of new products in turnover
Lower triangle: share of new and improved products in turnover

	INNOVEXP	INNOVEXP3	INNOVEXP2	INNOVEXP1
INNOVEXP		0.0175 (5.74)	0.0216 (5.10)	0.000304 (0.01)
INNOVEXP3	0.0513 (8.25)		0.00408 (1.07)	-0.0172 (-0.73)
INNOVEXP2	0.0543 (6.29)	0.00306 (0.39)		-0.0213 (-1.00)
INNOVEXP1	0.0471 (0.97)	-0.00417 (-0.09)	-0.00724 (-0.17)	

Notes: Upper triangle: entries denote estimates of the impact of the row-variable minus the impact of the column-variable on the share of new products in turnover. Lower triangle: entries denote estimates of the impact of the column-variable minus the impact of the row-variable on the share of new and improved products in turnover.

See text for explanation of the abbreviations of variable names.

t-statistics of differences in brackets. Asterisks mark differences whose t-statistics indicate statistical significance in a two-tailed test at the 5% level (one asterisks) respectively 10% level (two asterisks).

Table A.3. Does proximity matter for knowledge spillovers? Estimates of differences in impact (of percentage changes), logit model

Upper triangle: share of new products in turnover
Lower triangle: share of new and improved products in turnover

	INNOVEXP	INNOVEXP3	INNOVEXP2	INNOVEXP1
INNOVEXP		0.295 (4.87)	0.265 (3.15)	-0.545 (-1.15)
INNOVEXP3	0.587 (7.00)		-0.0297 (-0.39)	-0.840 (-1.80)
INNOVEXP2	0.451 (3.87)	-0.136 (-1.30)		-0.810 (-1.91)
INNOVEXP1	0.110 (0.17)	-0.478 (-0.74)	-0.341 (-0.58)	

Notes: Upper triangle: entries denote estimates of the impact of the row-variable minus the impact of the column-variable on the share of new products in turnover. Lower triangle: entries denote estimates of the impact of the column-variable minus the impact of the row-variable on the share of new and improved products in turnover.

See text for explanation of the abbreviations of variable names.

t-statistics of differences in brackets. Asterisks mark differences whose t-statistics indicate statistical significance in a two-tailed test at the 5% level (one asterisks) respectively 10% level (two asterisks).